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REACTIONS WITH LIGHT NUCLEI

ON THE EXCITED STATES OF He^4

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Experimental data concerning the excited states of He^4 are considered. The $\text{T}(p,n)\text{He}^3$ excitation function and neutron angular distributions have been measured from the threshold up to 12 Mev. The excitation function and the energy dependence of the angular distributions have a resonant character due to the 22 Mev excited state of He^4 . Neutron spectra at several angles and a proton spectrum at 30° of the $\text{T}+d$ and (He^3+d) reactions have been measured by the time-of-flight method at 18 Mev deuteron energy. The comparison of the $\text{T}+d$ and He^3+d spectra and cross sections confirms the existence of the excited state in He^4 and points to the absence of similar states in Li^4 and H^4 . Due to this fact the isotopic spin of the He^4 excited state is believed to be $T=0$.

MEASUREMENT OF THE ENERGY DEPENDENCE OF THE REACTIONS $\text{He}^3(n,p)$; $\text{Li}^6(n,\alpha)$; $\text{B}^{10}(n,\alpha)$ and $\text{N}^{14}(n,p)$

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A lead slowing down time neutron spectrometer was used to compare the energy dependence of the cross sections of the (n,α) and (n,p) reactions for energies up to 25 kev. The results of the measurements are compared with predictions that can be made on basis of data pertaining to the nuclear levels of Li^7 , B^{11} and N^{15} which are the nearest to the neutron binding energy. It is concluded that for $E < 25$ kev the

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cross section for the $B^{10}(n,\alpha)$ reaction does not depart from the $1/v$ law by more than 5 - 10%. For the $Li^6(n,\alpha)$ cross section the departure from $1/v$ is even less. The ratio for the $N^{14}(n,p)$ cross section to that for $Li^6(n,\alpha)$ is constant to within 3% up to ~5 kev; at higher energies it begins to increase. The increase is of the order of 10% at $E=25$ kev. The cross section ratios $He^3(n,p)/Li^6(n,\alpha)$ and $He^3(n,p)/B^{10}(n,\alpha)$ decrease with increasing energy, the magnitude of the dip exceeding 15% at $E=25$ kev. This signifies that the $He^3(n,p)$ cross section decreases with the energy considerably more rapidly than the $1/v$ law predicts. The energy dependence of the $He^3(n,p)$ reaction up to energies ~1 Mev can be satisfactorily described if an excited level with an angular momentum 0^+ is assumed to exist in the He^4 nucleus.

Analysis of variation of the $B^{10}(n,\alpha)$ cross section indicates the existence of a level in B^{11} which possesses an angular momentum $5/2^+$ or $7/2^+$, an energy $E_2 \sim 250$ kev and widths $\Gamma_\alpha \sim 400$ kev, $\Gamma_n \sim 200$ kev.

$Li^7(p,t) Li^5$ REACTION

N. A. VLASOV, A. A. OGLOBLIN

The triton spectra of $Li(p,t)$ reaction at several angles have been obtained with 12 Mev protons. The group of tritons corresponding to the ground state of Li^5 has been observed in all spectra. In the small angle region a peak has been observed on the continuous background due presumably to the $Li^7(p,p) Li^{7*} \rightarrow He^4 + t$ reaction, at the energy corresponding to the expected group of tritons associated with the excited state of Li^5 . The angular distribution of the main group of tritons shows that the $Li^7(p,t) He^5$ reaction proceeds essentially without formation of compound state. The total cross section of tritium production has been measured as a function of proton energy. It amounts to 250 mb at $E_p = 8$ Mev and remains approximately constant with further increase of energy.

SPECTRA OF NEUTRONS AND PROTONS FROM $He^4 + d$ REACTION AND ENERGY LEVELS OF Li^5 AND He^5

K. P. ARTEMOV, G. F. BOGDANOV, N. A. VLASOV,
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The energy spectra of neutrons and protons from the bombardment of He^4 by 18 Mev deuterons have been measured. Neutron spectra were studied by the time-of-flight

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method and proton spectra by the time-of-flight method as well as by the nuclear emulsion technique. Energy groups corresponding to the ground states of Li^5 and He^5 as well as continuous spectra due to the deuteron breakup have been observed. The shape of the spectra is discussed in connection with the problem of the existence of Li^5 and He^5 excited states at 2 - 3 Mev, on which there is no agreement in the literature.

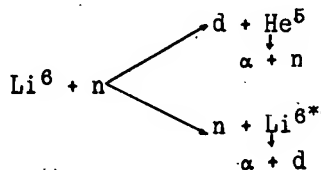
ENERGY LEVELS OF Li^6 AND He^5

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The interaction of fast deuterons (up to 17.5 Mev) and neutrons (14 Mev) with Li^6 and Li^7 nuclei has been studied using lithium impregnated nuclear emulsions. The adopted experimental method permitted the identification of reactions resulting in the emission of several particles. These reactions were shown to involve the formation of the following Li^6 levels:

$E_1^* = 2.2 \text{ Mev } (T = 0)$	$E_2^* \approx 4.5 \text{ Mev } (T = 0)$	$E_3^* \approx 5.2 \text{ Mev } (T = 1)$
$E_4^* \approx 5.7 \text{ Mev } (T = 0)$	$E_5^* \approx 6.7 \text{ Mev } (T = 1)$	$E_6^* \approx 7.5 \text{ Mev } (T = 0)$
$E_7^* \approx 8.3 \text{ Mev } (T = 0)^*$	$E_8^* \approx 9.3 \text{ Mev } (T = 0)$	$E_9^* \approx 10.0 \text{ Mev } (T = 0)$
$E_{10}^* \approx 10.7 \text{ Mev } (T = 0)$	$E_{11}^* \approx 11.7 \text{ Mev } (T = 0)(?)$	

Both channels of the reaction



were investigated, one of them involving the formation of He^5 . The formation of a He^5 nucleus in the ground state with $E \sim 1 \text{ Mev}$ with respect to $\alpha + n$ has been observed. The possible existence of an excited state of He^5 is discussed.

*According to some indications this level seems to have isotopic spin $T = 1$.

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(p,n) REACTION ON LITHIUM AND THE GROUND STATE OF Be⁶

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B.V. RYBAKOV, V.A. SIDOROV

The neutron spectra of (Li⁶ + p) and (Li⁷ + p) reactions have been studied by the time-of-flight method with 9 Mev protons. Groups of neutrons resulting from the (p,n) reaction due to the ground state of Be⁶ and to the three lower levels of Be⁷ have been observed, as well as a continuous distribution of low energy neutrons resulting from many-particle reactions. The observation of a neutron group from the Li⁶(p,n)Be⁶ reaction is the first experimental evidence of the existence of Be⁶. The energy of the Li⁶(p,n)Be⁶ reaction is 5.2 Mev and the width of the ground state is no more than 0.3 Mev. The differential cross sections have been measured for the angles of 0, 15, 30, 60 and 120°.

ON THE RADIUS OF THE ALPHA PARTICLE

I. LEVINTOV

The potential parameters of the α particle are estimated and compared on the basis of cross section and polarization data for protons scattered at low (≈ 10 Mev) and high (≈ 315 Mev) energies.

The α particle potential is chosen in the form

$$v_1 \rho(r) + v_2 \frac{1}{r} \frac{d\rho}{dr} (\vec{l}_1 \vec{\sigma})$$

where $\rho(r)$ is a function resembling nucleon density distribution; v_1, v_2 are real at low energies and complex at high energies. The potential is real at low energies due to the fact that the α particle is an especially compact system.

The reliability of the experimental data together with the specific properties of the α particle connected with its zero spin, small radius and high binding energy makes possible unambiguous analysis with sufficient accuracy.

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The following potential parameters were obtained for the p - He⁴ interaction:

Method	Shape of distribution	$r_0 \cdot 10^{13}$ cm	$ v_1 $ Mev	$\left \frac{v_2}{v_1}\right \cdot 10^{27} \text{cm}^2$
p - He ⁴ phase shifts 1 - 10 Mev	$\exp\left(-\frac{r^2}{r_0^2}\right)$	2.3	47	3.3
p - He ⁴ cross section and polarization, 315 Mev	$\exp\left(-\frac{r^2}{r_0^2}\right)$	1.8	24	3.3
Scattering of 185 Mev electrons	Uniform	1.6		-

It is especially interesting to note that the interaction radius r_0 decreases by 30% when the proton energy rises to 300 Mev. The pronounced decrease in the p-He⁴ radius observed already at $\beta \approx 0.7$ is a reflection of a general property of nuclear forces and is apparently related to the "delay" effects which should be inherent in the short range exchange forces.

INTERACTION OF LOW ENERGY DEUTERONS WITH DEUTERIUM AND TRITIUM

YU.G. BALASHKO, I.YA. BARIT

The scattering of low energy deuterons by deuterium and tritium and the D-T reaction at low energies of the bombarding particles have been studied. The flux of the bombarding particles in the scattering measurements has been determined from the yield of the nuclear reaction accompanying the scattering using previously obtained values of cross sections for the reaction. In order to eliminate foreign pulses (background, scattering on admixtures, etc.), coincidences between the scattered particles and recoil nucleus have been measured. The scattered particles were recorded with proportional counters which were not separated from the gaseous target by a window and which together with the target were filled to a pressure of 2 - 5 mm Hg.

D-D scattering has been measured at an angle $\theta = 56.5^\circ$ in the 100 to 600 kev energy range (laboratory system). The ratios of the measured effective scattering cross section to the effective cross section for scattering in a Coulomb field are listed below.

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E_d , kev	94	156	206	262	300	350	410	470	532	595
σ/σ_k	0.95 ± 0.12	1.06 ± 0.13	1.12 ± 0.08	1.29 ± 0.10	1.38 ± 0.12	1.35 ± 0.11	1.76 ± 0.13	1.85 ± 0.15	2.10 ± 0.16	2.60 ± 0.18

Analysis of the results of the measurements makes possible the estimation of the phase shift in the 6S_2 state. The effective scattering cross section can be described as a purely potential one.

D-T scattering has been measured at an angle of 90° in the c.m.s. and in the triton energy range from 100 to 700 kev. The results are listed in the table in the same units as those pertaining to D-D scattering:

N	E_T , kev	σ/σ_k
1	72 ± 2	0.64 ± 0.08
2	90 ± 2	0.62 ± 0.06
3	102 ± 2	0.54 ± 0.05
4	133 ± 2	0.55 ± 0.04
5	163 ± 2	0.63 ± 0.04
6	187 ± 2	0.77 ± 0.05
7	220 ± 5	1.12 ± 0.07
8	246 ± 3	1.35 ± 0.08
9	300 ± 4	1.82 ± 0.10
10	362 ± 5	2.50 ± 0.17
11	418 ± 6	3.20 ± 0.18
12	472 ± 5	3.60 ± 0.22
13	655 ± 7	4.81 ± 0.31

Measurements of the effective cross section for the D-T reaction were carried out by Katsaurov et al. by means of a differentially pumped gas target and a thin zirconium target. Use of a differentially pumped target permits an accurate determination of the magnitude of the cross section in the vicinity of its maximum. The measurements yielded a value of 107 ± 1 kev for the peak deuteron energy and $(5.22 \pm 0.1)10^{-24} \text{cm}^2$ for the effective cross section. The excited level in He^5 should also affect the scattering cross section. The latter was calculated for resonance parameters determined by analyzing the reaction taking into account potential scattering. The experimental scattering cross section values are close to those obtained from the computed curves but lower by some 10 - 20%. A study of D-T scattering along with the D-T reaction makes possible a better check of the applicability of the resonance theory to the lightest nuclei and presumably also a more precise determination of the resonance parameters of the He^5 level.

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MEASUREMENTS OF CROSS SECTIONS OF THE $B^{10}(p,\gamma)$ and $B^{10}(d,n)$ REACTIONS

A.K. WALTER, A.S. DEYNEKO, A.YA. TARANOV

The absolute cross sections of the $B^{10}(p,\gamma)$ and $B^{10}(d,n)$ reactions have been measured in the low-energy region of bombarding particles produced by the electrostatic accelerator.

The method of absolute cross section measurements of the above reactions consisted in the accumulation of the radioactive C^{11} nuclei in the bombarded target with a subsequent measurement of their radioactive decay. The positron activity was detected using a tube-electrometer of peculiar construction, a ring-type multi-filament counter and an end-window counter.

The reaction cross sections were measured at different energies of the bombarding particles:

for $B^{10}(p,\gamma)$ - in the 325 - 1500 kev range,
for $B^{10}(d,n)$ - in the 100 - 400 kev range.

The following values of the cross sections have been obtained at low energies of the bombarding particles:

$\sigma(p,\gamma) = 5 \cdot 10^{-31} \text{ cm}^2$ by $E_p = 350 \text{ kev}$,
 $\sigma(d,n) = 8 \cdot 10^{-29} \text{ cm}^2$ by $E_d = 95 \text{ kev}$.

SLOW NEUTRONS SCATTERING BY ORTHO - AND PARA-TRITIUM

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V.T. SMOLYANKIN, A.P. SOKOLOV, D.B. DIATROPTOV

The scattering cross sections of ortho- and para-tritium for slow neutrons have been determined by the transmission method. The measurements have been performed with an apparatus previously used for hydrogen and deuterium investigations. A method of production and of analysis of big quantities of ortho- and para-tritium in gas form has been developed. Palladium metal was used as a catalyst in ortho- and para-conversion. Special precautions for working with such high gas activities (20.000 curie) have been developed.

Two gas mixtures have been used to fill the scattering chamber:

- a) 75% ortho- and 25% para-tritium
- b) 35% ortho- and 65% para-tritium.

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The first mixture is at equilibrium at room temperature, the second at liquid hydrogen temperature.

The gas has been carefully purified since the presence of even a small admixture of H^3 (decay product of tritium) is very undesirable. Owing to its very large neutron cross section (3.10^4 barns) such an admixture can introduce considerable incertainties. Six runs have been made (three with each mixture).

The results are:

$$\begin{aligned}\sigma_{\text{ortho-tritium}} &= 4.5 \pm 1.0 \text{ barns} \\ \sigma_{\text{para-tritium}} &= 1.0 \pm 1.5 \text{ barns.}\end{aligned}$$

INTERPRETATION OF TRANSITION PROBABILITIES
FOR REACTIONS IN LIGHT NUCLEI

B. H. FLOWERS

Using the intermediate coupling methods of the shell model one can calculate transition probabilities for several kinds of nuclear reaction. Results will be presented for reduced widths of some (n, γ) and (d, p) stripping reactions in isotopes of Li, C, N, and O, for the β -decay of Li^8 , C^{14} , N^{16} , and O^{19} , and for some branching ratios and lifetimes of γ -ray emitting levels. Particular attention is given to the enhancement of electric quadrupole transitions due to collective vibrations of the core.

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POLARIZATION EFFECTS AT NUCLEAR REACTIONS

SOURCES OF POLARIZED PARTICLES

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The study of spin dependence of nuclear forces is of great importance. Experiments on polarization effects occurring in nuclear reactions require double and sometimes triple scattering which presents great experimental difficulties.

Modern types of accelerators make it possible to accelerate beams of polarized particles without practically any depolarization of these particles in the process of acceleration.

The construction of sources of polarized particles may be based on the following principles:

- a) the use of nuclear scattering;
- b) the polarization of atoms through electronic spin;
- c) the use of metastable states $^2S_{1/2}$.

The report discusses intensities which may be achieved with sources of this type as well as several source designs.

POLARIZATION OF PROTONS SCATTERED BY O^{16} SPIN AND PARITY OF THE 3.11 Mev LEVEL OF THE F^{17} NUCLEUS

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K.V. KARADJEV, V.I. MANKO, A.Y. TARANOV

The study of polarization produced in the elastic scattering of protons in the 2.6-2.8 Mev range by O^{16} has been undertaken with the aim of determining the moment and parity of the 3.11 Mev state of the F^{17} nucleus.

The degree of polarization of the proton beam after scattering by oxygen nuclei was determined from the asymmetry in the elastic scattering by He^4 . It was shown

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that the 3.11 Mev state of the F^{17} nucleus corresponds to spin 1/2 and negative parity.

Calculations of the polarization in the elastic scattering of protons by O^{16} have been performed for the energy range up to 5 Mev. It was shown that polarization measurements at energies exceeding 3 Mev are of considerable interest for the identification of the F^{17} nucleus levels.

SMALL-ANGLE SCATTERING OF D-D NEUTRONS BY Pb

G.V.GORLOV, N.S.LEBEDEVA, W.M.NOROSOV

The asymmetry of neutron scattering by Pb and Be at $2^\circ - 4^\circ$ was investigated. 3.85 Mev D-D neutrons, emitted at 45° with respect to the incident deuteron beam ($E_d^* = 1$ Mev), were studied. By means of a wedge collimator and a target, imitating a line source a sharply defined neutron beam with angular divergence of 1° was obtained.

Scattered neutrons were detected with a styrene scintillation counter.

A strong background, consisting for the most part of γ -ray counts, presented the main experimental difficulty. A massive lead shielding surrounded with paraffin-borax blocks was used. Nevertheless, the background amounted to $\approx 50\%$ of the total counting rate.

The azimuthal asymmetry of neutron scattering in the D-D plane was observed, from which the lower limit of neutron polarization at $E_d = 1$ Mev was evaluated to be $(16 \pm 8)\%$.

THE POLARIZATION OF γ -RADIATION FROM THE $Si^{30} (p, \gamma) P^{31}$ REACTION

P.M.TUTAKIN, S.P.TZITCO, V.J.GONCHAR,
A.K.WALTER, A.N.LNOV

The polarization of high-energy γ -rays from the $Si^{30} (p, \gamma) P^{31}$ reaction at proton energies $E_p = 773; 939$ and 979.5 kev was measured.

(H^+) protons accelerated in the electrostatic accelerator and thin targets ($15 - 20$ mg/cm²) of the magnetic-separated isotope Si^{30} were used. γ -rays emitted at 90° to the proton beam were detected using nuclear emulsions impregnated with heavy water.

* E_d - deuteron energy.

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The azimuthal angular distributions of the photo-proton tracks are given by the expression $W(\varphi) = 1 + (R - 1) \cos^2 \varphi$, where R is the ratio of the intensity of γ -radiation polarized in the plane of the incident proton and the emitted γ -ray, to the intensity of γ -radiation polarized at right angle to this plane.

For electric dipole radiation $R_{E1} = \frac{1-a}{1+a}$ and for magnetic dipole radiation $R_{M1} = \frac{1+a}{1-a}$, where a is the coefficient at $\cos^2 \varphi$ in the angular distribution of the γ -radiation.

The obtained values of R made possible the determination of the type of γ -radiation, and hence of the parity of the highly excited states of the p^{31} nucleus.

E_{p1} keV	a	R_{E1}	R_{M1}	R	Type of γ -radiation	Energy levels of the excited p^{31} nucleus	Spin and parity
773	-0.5	3.0	0.4	3.8	E 1	8.04	$3/2^-$
939	-0.6	4.0	0.3	0.5	M 1	8.20	$3/2$
979.5	-0.5	3.0	0.4	2.9	E 1	8.24	$3/2^-$

POLARIZATION EFFECTS IN LIGHT NUCLEI REACTIONS

Y.A. SMORODINSKY, A.I. BAZ

In principle the problem of construction of a wave function of some nuclear system may be divided into two parts: first, determination (from experimental data) of boundary conditions at a nuclear surface and, second, construction (from the boundary conditions) of the complete wave function of the system. We shall consider only the first part of the problem.

Detailed analysis, carried out for two particles with spin $1/2$ shows that:

1) in the case of pure elastic scattering, in order to determine the values of the wave function and its derivative at the nuclear surface, one has to examine not only the differential cross section of scattering but also the polarization and the correlation of polarizations of both particles, it being sufficient to make experiments with one, two and three scatterings;

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2) in the case where some inelastic channels are open, the analysis of the elastic scattering alone cannot give enough information to determine the boundary values. One has to make joint analysis of the experimental data on the elastic and inelastic processes. The total number of experiments one has to make depends on the properties of the system. For example, this number is strongly reduced if charge invariance of nuclear forces is assumed.

These results may be generalized for higher spins.

MEASUREMENT OF POLARIZATION OF NEUTRONS FROM THE D+T REACTION AT $E_d = 1800$ kev

J.J.LEVINTOV, A.V.MILLER, V.N.SHANSHEV

Polarization was measured at neutron emission angles of 45° ; 67.5° ; 90° ; 112.5° ; 135° (c.m.s.) by observing the azimuthal asymmetry of neutrons scattered by helium in thin directional proportional counters. (A detailed description of the analyzer is presented in Zhur. Esp. Teor. Fiz. 32, 274 (1957) and Nuclear Physics 3, 221, 1957)

Tantalum targets of 30 kev thickness saturated with tritium were used. The angle of rotation of the counters was 22° . Efficiency of the analyzer was 0.8 - 0.9. The following preliminary results were obtained:

Angle	45°	67.5°	90°	112.5°	135°
Neutron polarization, %	7 ± 3	12 ± 5	10 ± 3	2 ± 3	0.0 ± 5

MEASUREMENT OF POLARIZATION OF PROTONS FROM THE D + D REACTION

I.V.YEREMINA, J.J.LEVINTOV, A.N.MALYSHKO,
V.G.NIKOLSKY

A thin zirconium target saturated with deuterium was bombarded with a deuteron beam of 1800 kev energy.

Protons emitted from the target at an angle of 110° in the laboratory system entered an end window counter filled with helium. Protons which were scattered in helium at angles of $75-105^\circ$ were detected by means of cylindrical proportional counters filled with argon.

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The pulses from the helium and argon counters were fed to coincidence circuits. Proton polarization was determined from the scattering asymmetry of the protons in helium. In order to exclude any possible effect due to asymmetry in the analyzer geometry the whole arrangement was periodically revolved 180° about the axis of the end window counter. An analyzer of this type permits the study of proton polarization in presence of a large neutron background.

The measured polarization for $E_d = 1800$ kev was $13\% \pm 5\%$.

The Brinkleworth-Rose polarization parameters were employed in the calculations of $p - \alpha$ scattering.

INVESTIGATION OF POLARIZATION OF PROTONS ELASTICALLY SCATTERED FROM C^{12}

A.K.WALTER, P.W.SOROKIN, A.JA.TARANOV

The polarization of protons elastically scattered by C^{12} nuclei has been investigated in the 1.7-2.5 Mev range of bombarding energies in the laboratory system at 30° , 40° , 60° and 90° scattering angles in the c.m. system.

The polarization was determined from data on the azimuthal asymmetry of protons after secondary scattering in helium gas.

Obtained values were compared with values calculated on the basis of the phase-shift analysis for protons scattered by C^{12} .

Experimental and calculated values agree to within the accuracy of the experiments.

RECENT POLARIZATION EXPERIMENTS ON THE HARWELL CYCLOTRON

B.H.FLOWERS

The depolarisation of polarised 140 MeV protons in pp collisions has been measured by the Harwell cyclotron group as a function of scattering angle. The results are in good agreement with the Marshak potential, but not with the Gammel-Thaler potential.

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NEUTRON REACTIONS

INTERACTIONS OF SLOW NEUTRONS WITH NUCLEI

*V.V. VLADIMIRSKY, A.A. PANOV, I.A. RADKEVICH
AND V.V. SOKOLOVSKY*

The report presents slow neutron resonance parameter data. The experimental data are compared with the different nuclear models.

CHARACTERISTICS OF A LEAD SLOWING DOWN TIME SPECTROMETER AND MEASUREMENT OF CROSS SECTIONS FOR THE (n, γ) REACTION

*A.A. BERGMAN, A.I. ISAKOV, YU.P. POPOV AND
F.L. SHAPIRO*

By employing a scintillation counter with a controlled multiplier for registration of capture γ -rays and using a time analyzer with a 0.5 μ sec channel width it has been possible to investigate in the hundred-thousand ev energy range the characteristics of the slowing down time spectrometer. Measurements of the energy dependence of the capture cross sections for substances with widely spaced levels (Al, Cl, Na, Fe, Ni, Cu, Bi, Pb, Mn, Mo) were performed with the purpose of determining the resolving power and the dependence of the mean neutron energy on the slowing down time. Results of the measurements are presented and discussed. Levels at 1200 ± 100 ev in Fe and 1700 ± 150 and 2800 ± 200 ev in Pb were detected; the existence of a level at 405 ev in Cl is confirmed. The 405 ev level is manifest in the (n, γ) as well as (n, p) reactions. An energy value, which appreciably differs from those presented in other papers, has been obtained for the negative level in chlorine. The width ratio Γ_p/Γ_γ for the negative level is much smaller than that for the 405 ev level.

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FAST NEUTRON CAPTURE CROSS SECTIONS IN THE REGION OF
"MAGIC" NUCLEI

YU. V. GOPMAN, M. V. PASECHNIK

The monoenergetic neutron capture cross sections have been measured at the energies 2.5, 3.1 and 4.0 Mev using the activation method. The capture cross sections of I^{127} have been used as standart cross sections. They are equal to 51, 44 and 37 mb at 2.5, 3.1 and 4.0 Mev respectively. The obtained results are compared with data of other authors and presented as a function of energy and mass number (Table 1).

Table 1

Capture cross sections in mb

Z	Nucleus	Half-life	2.5 Mev	3.1 Mev	4 Mev
1.	Ti ⁵⁰	5.79 min	0.82	0.73	0.7
2.	Cu ⁶⁵	5.1 "	4.2 ± 0.32	3.9 ± 0.31	3.5 ± 0.3
3.	Ga ⁶⁹	20.3 "	13 ± 1.5	12.3 ± 1.8	12 ± 1.3
4.	Ge ⁷⁴	82 "	10 ± 0.7	7.5 ± 0.6	6 ± 0.5
5.	Rb ⁸⁷	17.7 "	1.5 ± 0.4	1.4 ± 0.3	1.1 ± 0.2
6.	Mo ¹⁰⁰	14.6 "	6.3 ± 1.2	5.6 ± 1.0	4.5 ± 0.7
7.	Rh ¹⁰³	44 sec	54.7 ± 4.5	43.5 ± 3.2	34.8 ± 2.7
8.	Rh ¹⁰³	4.7 min	9.8 ± 1.9	8.9 ± 1.4	7.7 ± 1.1
9.	Pd ¹¹⁰	22 "	22.1 ± 2.0	20 ± 1.8	16.2 ± 1.6
10.	Sn ¹²²	40 "	7.5	6.5	5.7
11.	Te ^{128,130}		12.4 ± 3.3	10.1 ± 3.0	7.2 ± 2.1
12.	Ba ¹³⁸	85 min	1.1 ± 0.5	1.0 ± 0.4	0.74 ± 0.3
13.	Pr ¹⁴¹	19.1 h	8.6 ± 0.4	7.1 ± 0.3	6.3 ± 0.2
14.	W ¹⁸⁶	24 "	30	24	19
15.	Tl ²⁰⁵	4.2 min	5.2 ± 0.3	5.07 ± 0.2	5.1 ± 0.2

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SMALL ANGLE SCATTERING OF FAST NEUTRONS BY HEAVY NUCLEI

YU. A. ALEXANDROV

Nuclear forces make the main contribution to neutron cross-section scattering. Moreover, a number of supplementary effects due to electromagnetic interactions of neutrons with nuclei should be expected, in particular the interaction of magnetic and electric (induced and possibly intrinsic) neutron moments with the electric field of the nuclei. The contribution of above mentioned phenomena to the scattering cross-section will be the greatest for neutron scattering by heavy nuclei. It must manifest itself in the abnormal behaviour of the small angle differential cross section since electromagnetic forces act within a longer range than nuclear forces.

The interaction of the magnetic neutron moment with an electric nuclear field has been theoretically investigated by Schwinger, Sample and Baz. For the purpose of experimental detection of this phenomenon the angular distribution of mean energy neutrons $\sim 3 - 4$ Mev scattered by Pb and Cu in the angular interval between 0.7° and 8° has been investigated. In the region of angles 2° for Pb ($Z = 82$) an increase in the cross section, characteristic of the scattering predicted by Schwinger has been observed.

More accurate measurements of the angular distribution of neutrons scattered by U, Pb, Sn and Cu nuclei in the angular interval from 0.6° to $10^\circ - 12^\circ$ have been undertaken. For U and Pb the course of the cross section curve noticeably differs from the theoretical curve.

The problem of the existence of a neutron intrinsic electric dipole moment has been discussed in the literature at an earlier date as well as recently. It follows from Smith's experiments that the intrinsic neutron electric moment, if it exists at all, must be $\leq 5 \cdot 10^{-21} e$ CGSE. Evaluations show that the contribution to the cross section scattering due to the existence of a neutron electric moment of this order of magnitude is negligibly small.

In a strong electric field the deformation of the meson cloud of the neutron may give rise to an electric moment.

Preliminary theoretical investigations of this phenomenon were carried out by Barashenkov and others. It follows from their works that the polarizability coefficient $\alpha \approx 10^{-41} \text{ cm}^3$. At this value of α the effect may be noticed in small angle neutron scattering by heavy nuclei.

Measurements of the angular neutron distribution of 2 Mev mean energy scattered by Pu, U, Pb, Bi, Sn and Cu nuclei in the angular interval from 3° to 25° have been undertaken. For Pu and U a strong increase of the cross section region of angles 11° .

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that cannot be explained by Schwinger scattering has been observed. This increase of the cross section may be tentatively attributed to the existence of neutron "polarizability".

INELASTIC SCATTERING OF NEUTRONS BY SPHERICAL NUCLEI

A. N. KOROLYOV

The present paper deals with the inelastic scattering by spherical nuclei taking into account the collective excitation of the nuclear surface on the basis of A. Bohr's unified nuclear model. The intermediate states of the compound nuclei are neglected. Tamm-Dankov's method is used and the nonstationarity of the process is taken into consideration on the basis of Heitler's damping quantum theory.

The wave function of a system consisting of a neutron and a target nucleus is considered in the representation of the occupation number of excitation quanta of the nuclear surface (phonons) and is expanded in a series of the eigenfunctions of unperturbed problem. Substituting this expansion in Schrödinger's equation we obtain a system of infinite number of connected integral equations for different quantum state amplitudes in the p -representation. Cutting off the obtained equation system at amplitudes with the number of phonons $n \geq 3$ and taking into account that the collective interaction of a neutron with a nucleus takes place at the surface of the nucleus we obtain the solution for the state amplitudes.

In the present case the obtained integral equation system for the state amplitudes is solved with high precision without introducing any supposition about the interaction constant with nuclear surface. The obtained energy dependence of neutron inelastic scattering cross section coincides with the well-known dispersion formula. It has maxima at resonance energies and is characterized by the half-width $T(E_n)$. This means that quasistationary intermediate states with finite lifetime may exist in the case of direct interaction. They, however, differ essentially from the compound nucleus states. The angular distribution of neutrons due to direct interaction will differ from that of inelastically scattered neutrons associated with the formation of compound nucleus.

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DETERMINATION OF NUCLEAR ENERGY LEVELS FROM INELASTIC
SCATTERING OF FAST NEUTRONS

I. F. BARCHUK, M. V. PASECHNIK, YU. A. TSYBULKO

The energy levels of a target nucleus are excited due to the inelastic scattering of fast neutrons. The energy levels may be investigated by measuring the γ -ray spectra from de-excitation of the nuclei.

The present paper reports on measurements of the γ -ray spectra excited due to the inelastic scattering of 2.8 Mev neutrons from the reaction $D(D,n)He^3$ in Mg, Al, Fe, Cu, Sn and Sb. The spectrometer used for the γ -ray spectra measurements consisted of a NaI(Tl) scintillation crystal, a FEU-1B photomultiplier, a conventional amplifier and a 50-channel pulse height analyzer with a magnetic recording mechanism. The spectrometer resolution was 6.5 - 7% for Co^{60} γ -rays (1.17 and 1.33 Mev).

The ring scattering geometry was used.

The following data have been obtained for the energy of γ -rays (in Mev):

Mg: 0.97; 1.41; 1.92; 2.3
Al: 0.84; 1.00; 1.80; 2.16
Fe: 0.84; 1.25; 1.46; 1.70
Cu: 0.63; 0.78; 0.96; 1.12; 1.38; 1.46; 1.72; 2.03
Sn: 0.84; 1.16; 1.50; 1.80; 2.16
Sb: 1.04; 1.50; 1.84; 2.16.

The relative intensities of γ -rays have been evaluated for each element independently.

A good agreement between our data and data obtained by other authors has been obtained for Mg, Al, Fe and Cu. Apparently the spectrum of Sb γ -rays has not been investigated before.

SEARCH FOR NEW REACTIONS INDUCED BY FAST NEUTRONS

YU. A. GRITS, D. E. KHULELIDZE, I. P. SELINOV,
V. S. ZOLOTAREV

Nuclear reactions induced by fast neutrons on separated germanium isotopes were investigated:

- a) $Ge^{72}(n, \alpha)Zn^{69}$
- b) $Ge^{73}(n, p)Ga^{73}$

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c) $\text{Ge}^{74}(\text{n}, \text{p})\text{Ga}^{74}$

d) $\text{Ge}^{76}(\text{n}, \text{p})\text{Ga}^{76}$

e) $\text{Ge}^{72}(\text{n}, 2\text{n})\text{Ge}^{71}$.

Radioactive isotopes obtained on separated selenium isotopes (Se^{80} and Se^{82}) as a result of (n, α) , (n, p) and $(\text{n}, 2\text{n})$ reactions were also examined.

A table of possible nuclear reactions induced by fast neutrons is presented.

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DEUTERON REACTIONS

DIFFRACTIONAL DESINTEGRATIONS OF DEUTERONS AND THE STRIPPING REACTIONS

A.I. AKHIEZER, A.G. SITENKO

The interaction of deuterons with nuclei may be investigated by means of the optical model in the energy range of the order of several scores of Mev. Within this energy range the following processes due to the interaction between deuterons and nuclei are possible: absorption and scattering of the deuteron, stripping of the neutron or the proton and diffractive disintegration of the deuteron.

In the case of absolutely black nucleus a theory of the stripping reaction taking into account the finite radius of the nucleus may be developed. The integral cross section of the stripping reaction is then:

$$\sigma_n = \sigma_p = \pi R^2 \left\{ 1 - 2 \int_0^{\frac{P}{\xi}} \frac{P}{\xi} \arctg \frac{\xi}{P} \frac{I_1^2(\xi)}{\xi} d\xi \right\},$$

where $P = \frac{R}{R_d}$ (R and R_d are the radii of the nucleus and of the deuteron). The energy distribution of the released particles (neutrons or protons) is determined by the expression:

$$d\sigma_n(k_z) = F(k_z) dk_z, \quad k_z = \frac{E - \frac{1}{2} E_0}{\hbar \sqrt{E_0/M}},$$

$$F(k_z) = \frac{8\pi R^2}{\pi} \int_0^1 k_0^2 \left(p\xi \sqrt{1 + \frac{k_z^2}{\alpha^2}} \right) (\arcsin \xi + \xi \sqrt{1 - \xi^2}) \xi d\xi,$$

where E_0 is the energy of the incident deuteron and M is the mass of the neutron.

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In the limiting case $p \gg 1$ these formula coincide with the result obtained by R. Serber. Due to the stripping reaction the absorption cross section of the deuterons by black nuclei is found to be smaller than the geometrical cross section of the nucleus and is determined by expression:

$$\sigma_a = 2\pi R^2 \int_0^\infty \frac{p}{\xi} \operatorname{arctg} \frac{\xi}{p} \frac{I_1^2(\xi)}{\xi} d\xi.$$

In the limiting case $p \gg 1$ this cross section is equal to $\pi R^2 - \frac{\pi}{2} R R_d$.

DEPENDENCE OF THE $\text{Ca}^{40}(\text{d}, \text{p}) \text{Ca}^{41}$ REACTION CROSS-SECTION ON DEUTERON ENERGY

V.G. NEUDACHIN, I.B. TEPOV

All existing theoretical calculations of reaction stripping cross section for deuterons of low energies (0-20 Mev) are based on the perturbation theory, although it is well known that the perturbation theory is not applicable in this range. The calculated angular distributions are in good agreement with the experimental results. The form of the angular distributions seems, however, to show comparatively little sensitivity to any variants of theory. The value of total cross section and its change depending on the incident deuteron energy is much more sensitive. However, a comparison of the calculations on the perturbation theory with experimental data in this direction has never been attempted, although it would be of interest for the development of a more satisfactory theory of the stripping reaction to determine in what way the results of perturbation theory differ from experimental data and how great this difference is.

The present paper reports experimental values of the total cross section of $\text{Ca}^{40}(\text{d}, \text{p})\text{Ca}^{41}$ leading to the formation of a residual nucleus in the ground state (the neutrons are captured, in this case, with $l=3$). The obtained results are compared with different calculation variants according to the perturbation theory. The experimental data obtained for three values of deuteron energy (1.35, 2.18 and 4.0 Mev) using nuclear emulsions are given in the second line of the table.

Theoretical calculations were performed, taking into account the Coulomb interaction for different variants of deuteron-nucleus and proto-nucleus interactions (deuteron and proton scattering by a hard sphere adsorption of protons with $l < l_0$, etc). Results of calculations for two cases are exemplified in the table: the Coulomb interaction only; the Coulomb interaction and deuteron and proton scattering by a hard sphere.

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Table

E_d (Mev)	1.35	2.16	4.0	5.0
$\sigma_{exp.}$ (mb)	0.040	2.2	2.1	-
$\sigma_{theor.}$ (mb) ("Coulomb")	0.018	0.45	320	8200
$\sigma_{theor.}$ (mb) ("Coulomb" + "hard sphere")	0.010	0.16	80	1700

The obtained results show that there is no satisfactory agreement between the theoretical and experimental excitation curves. There is a significant difference both in the order of the crosssection value and in the excitation curve shape.

DEPENDENCE OF ANGULAR DISTRIBUTIONS IN STRIPPING REACTIONS UPON THE CHARGE OF THE TARGET NUCLEI.

I. B. TEPLOV, B. A. YURIEV.

The nuclear emulsion technique was used to obtain the angular distributions of long-range proton groups arising in the following nuclear reactions $P^{31}(d,p)P^{32}$, $S^{32}(d,p)S^{33}$, $Cl^{35}(d,p)Cl^{36}$, $K^{39}(d,p)K^{40}$ and $Ca^{40}(d,p)Ca^{41}$, as well as these of the proton group, corresponding to the formation of Si^{29} in the first excited state from the $Si^{28}(d,p)Si^{29}$ reaction. 4 Mev deuterons accelerated on a 72 cm cyclotron of the Moscow University were used.

In the investigated reactions in Si^{28} , P^{31} , S^{32} , and Cl^{35} the neutron is captured in the $1d_{5/2}$ state i.e. with orbital moment $l=2$. Therefore the angular distributions in the above reactions should be similar. However, the obtained angular distributions noticeably differ from one another. A sharply-marked secondary peak almost equal in height to the main peak has been observed besides the main peak in the angular distribution of protons arising in the $S^{32}(d,p)S^{33}$ reaction. For the silicium reaction a comparatively small height of the main peak as compared with the isotropic part of the angular distribution has been observed. The most reasonable explanation of the observed differences is the assumption that the mechanism of formation of the compound nucleus greatly affects the angular distributions.

In the $K^{39}(d,p)K^{40}$ and the $Ca^{40}(d,p)Ca^{41}$ reactions the angular distributions are almost similar. Since previously published data show that $l=3$ in the calcium reaction, it may be concluded that in the case of potassium the neutron is captured with $l=3$ thus confirming the prediction of the shell model. However, it was impossible to determine the value of l by direct comparison of the experimental

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results with the angular distributions calculated in accordance with the simple stripping theory (Butler theory), owing to a significant shift of the main maximum (approximately 30°) towards small angles. A similar although less noticeable maximum shift (of a few degrees), occurs also in the first four reactions. It may be presumed that for 1 Mev deuterons the simple stripping theory could be applied in the range $Z < 18$ (at least for $l=2$ and $l=3$).

Angular distribution was also obtained for the $\text{Ca}^{40}(\text{d}, \text{p}) \text{Ca}^{41}$ reaction with deuteron energy of about 2.2 Mev. In this case the maximum of the differential cross section proved to be near 0° , which means a still further increase of the shift.

STUDY OF INELASTIC SCATTERING OF DEUTERONS BY Li^7 , F^{19} , Na^{23} , Mg^{24} , Al^{27} NUCLEI.

E. A. ROMANOVSKY, G. F. TIMUSHEV.

Up to the present data on the inelastic scattering of deuterons by atomic nuclei at $5 < E_d < 15$ Mev are scarce and incomplete.

There is still no unambiguous theoretical explanation of these data. In the $E=5$ Mev range experimental data on inelastic scattering of deuterons are almost completely lacking. This paper presents the results of experimental and theoretical investigation of inelastic scattering of deuterons with $E_d < 5$ Mev from a series of light nuclei (Li^7 , F^{19} , Na^{23} , Mg^{24} , Al^{27}).

The deuterons were accelerated on the 72-cm cyclotron. Groups of inelastically scattered deuterons have been analyzed using an analyzing magnet with high luminosity and good resolution power, which made possible an exact determination of their energies.

Differential cross sections of elastic and inelastic scattering of deuterons have been determined for $\theta_{\text{lab.}} = 91^\circ$.

The differential cross section of 0.475 Mev level of Li^7 bombarded by deuterons with $E_d = 4.54$ Mev is 35 mb/sterad. When bombarding F^{19} by deuterons with energies 4.49 and 4.05 Mev groups of deuterons were detected, corresponding to F^{19} levels: 0.197; 1.355; 1.410; 1.558 Mev with $\frac{d\sigma}{d\Omega}$ ($E_d = 4.49$ Mev) equal to: 16; 2; 2; 8.6 mb/sterad. respectively. For 0.439 Mev level of Na^{23} $\frac{d\sigma}{d\Omega} = 9$ mb/sterad. ($E_d = 4.48$ Mev). The excitation cross sections of 0.843 and 1.013 Mev levels of Al^{27} ($E_d = 4.49$ Mev) are 2 per cent and 3.5 per cent from the elastic

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scattering cross section. Excitation cross section of 1.37 Mev level of Mg^{24} is 14 per cent, at $E_d = 4.48$ Mev.

The obtained cross sections of inelastic scattering of deuterons are compared with theoretically obtained cross sections and a series of conclusions on relative probabilities of different competing mechanisms of the process of inelastic scattering are derived.

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COULOMB EXCITATION OF NUCLEI
AND PROTON REACTIONS

THE COULOMB EXCITATION OF NUCLEI

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1. Investigation of the Coulomb excitation of nuclei by cyclotron accelerated nitrogen ions.

The ratio of cross-section values for the Coulomb excitation of nuclear levels by heavy ions and protons was calculated. In some cases the use of heavy ions for the Coulomb excitation has advantages over the use of protons and alpha-particles. This was checked experimentally by using triply charged nitrogen ions accelerated in a cyclotron to 15.6 Mev. The current on the external target was equal to 0.2 - 0.5 μ A. The gamma-radiation was investigated with a scintillation spectrometer connected to a 50-channel pulse height analyzer. Nuclear levels were excited in 19 elements. The highest energy of excited levels was equal to ~600 kev.

Data obtained confirmed the preliminary calculations. The relative value of the X-ray background was found to be considerably lower than when working with protons. For all the nuclei with $Z \leq 9$, lines that could be ascribed to nuclear reactions were not discovered in spectra.

It was further shown that the values of the reduced probability of transition, $B(E2)$, obtained by us are in good agreement within experimental errors with the values obtained by other authors with protons and alpha-particles.

During the investigation of the Coulomb excitation by nitrogen ions with an energy of 25.4 Mev, for the majority of elements we have observed lines with $E \approx 1.3 - 1.8$ Mev and 2.3 Mev. Preliminary considerations about the nature of these lines are given.

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2. Investigation of Coulomb excitation of nuclei by cyclotron accelerated alpha-particles.

a) The Coulomb excitation of separated tin isotopes.

For the excitation of nuclear levels of tin alpha-particles with energies from 10.2 to 14.5 Mev were used. Separated isotopes of tin in the form of metallic samples were used as targets.

The results of investigation of even-even tin isotopes are given in table I. Here ΔE = the energy of the first excited level according to our data, ΔE^* = the energy according to data known from investigations of beta-decay or the (n,n') reaction, $B(E2)$ = the experimental value of the reduced probability of the electric quadrupole transition from the ground to the first excited level, τ = life time of the first excited level calculated from the experimental values of $B(E2)$ obtained by us.

In the bombardment of Sn^{117} , lines with $E = 0.162, 0.865$ and 1.03 Mev were found; in the bombardment of Sn^{119} , a line with $E = 0.907$ Mev. With Sn^{115} we have not discovered any lines.

Table 1

N°	Isotope	ΔE , Mev	ΔE^* , Mev	$\frac{B(E2)}{e^2} \cdot 10^{48} \text{ cm}^4$	$\tau \cdot 10^{13} \text{ sec.}$
1	Sn^{112}	1.26		0.18	7.0
2	Sn^{114}	1.30	1.30	0.20	5.2
3	Sn^{116}	1.29	1.27; 1.30	0.19	5.9
4	Sn^{118}	1.22		0.19	7.8
5	Sn^{120}	1.18	1.18; 1.30	0.17	10.2
6	Sn^{122}	1.15	1.14	0.15	12.7
7	Sn^{124}	1.13		0.14	15.1

b) The Coulomb excitation of separated nickel isotopes. Alpha-particles accelerated in the cyclotron to $E = 7.2$ Mev were used. The results of the investigation are given in Table 2.

Table 2

N°	Isotope	ΔE , Mev	$\frac{B(E2)}{e^2} \cdot 10^{48} \text{ cm}^4$	$\tau \cdot 10^{13} \text{ sec.}$
1	Ni^{58}	1.45	0.049	13
2	Ni^{60}	1.33	0.054	18
3	Ni^{62}	1.19	0.061	28
4	Ni^{64}	1.35	0.037	25

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c) Preliminary results on the investigation of the Coulomb excitation of Rb^{87} , Cd^{106} , isotopes of zinc and zirconium by means of alpha-particles accelerated in the cyclotron to $E = 7.2$ Mev were obtained.

GAMMA RADIATION PRODUCED IN INELASTIC SCATTERING
BY INTERMEDIATE WEIGHT NUCLEI

A.K. WALTER, I.I. ZALUBOVSKI, A.P. KLJU-
CHAREV, V.A. LUZIK

The excitation function and angular distribution of gamma-quanta produced, in proton bombardment of different targets has been investigated by means of a scintillation gamma-spectrometer.

The proton energy varied within the 1.8-3.4 Mev range.

Targets made of chromium, manganese, nickel and germanium natural isotopic mixture, as well as targets enriched with Fe^{54} , Cu^{63} , Cu^{65} and Zn^{66} were used.

A great number of gamma-lines were observed, some of them for the first time. An analysis of gamma transitions for Cu^{65} enabled us to build a diagramme of lower levels for Zn^{65} , which slightly differs from previously published variants.

A calculation of the energy of the original state of Cu^{65} shows that it is satisfactorily described by the model of a non-spherical nucleus with a negative deformation.

An attempt has been made to determine the origin of the 503 and 648 kev gamma-lines and to explain the great level width (1380 kev) of iron - 55.

ELASTIC CROSS SECTIONS FOR 19.8 Mev PROTONS
SCATTERED BY Co^{59} , Pb^{207} , Pb^{208} , Bi^{209} and U^{238}

R.A. VANETSIAN, A.P. KLJUCHAREV,
E.D. FEDCHENKO

As source of protons a linear accelerator was used and a beam of protons then obtained was biased and then collimated. Targets consisting of thin foils were placed in the scattering chamber and the scattered protons were registered by a photomultiplier provided with a NaI(Tl) crystal.

The differential cross section for all of the nuclei observed was measured within the angle interval of $20^\circ - 160^\circ$ with an accuracy of $\sim \pm 6\%$.

The following results were obtained for Co: the differential cross-section has two sharp minima of 720° and 117° and two maxima at 87° and 150° respectively.

The dependence of cross sections on angles for Pb^{207} and Pb^{208} is analogous but the location of minima and maxima is slightly displaced toward lesser angles. In

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the differential cross section for Si the maximum in the interval of $70^\circ - 80^\circ$ did not manifest itself sharply and the location of the other maximum and minimum is still more displaced toward lesser angles than for Pb^{208} . For U^{238} the differential cross section was found to be strongly smoothed and it did not show sharp maxima except for angles of $70^\circ - 80^\circ$ where smoothed maximum was observed.

INVESTIGATION OF γ -RADIATION FROM THE $\text{Si}^{30}(\text{p}, \gamma)\text{P}^{31}$ REACTION

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A.N.LNOV, A.K.WALTER, J.P.ANTUFJEV,
E.G.KOPANETZ

The $\text{Si}^{30}(\text{p}, \gamma)\text{P}^{31}$ reaction and γ -radiation from excited states of P^{31} has been studied. The differential and integral excitation functions, the spectra and the angular distributions of γ -rays as well as the absolute values of the reaction yields for some resonances have been measured.

The resonances at $E_p = 500; 619.5; 668; 675; 757; 773; 832.5; 939; 956.5; 975.5$ and 979.5 kev have been observed, using protons, accelerated in the electrostatic accelerator, and thin targets ($5-10 \mu\text{g}/\text{cm}^2$) of the magnetically separated isotope Si^{30} , as well as thick targets from natural mixture of silicon isotopes.

The obtained results for the excitation function and the absolute values of the reaction yields are tabulated below (Table 1)

Table 1.

E_p (kev)	W (Mev)	J	$Y \cdot 10^{10}$
500	7.774	-	-
619.5	7.890	0.90	7.1
668	7.937	0.10	-
675	7.943	0.05	-
757	8.023	0.10	-
773	8.038	0.32	2.9
832.5	8.086	0.12	-
939	8.199	0.45	3.3
956.5	8.216	0.10	-
975.5	8.224	0.25	-
979.5	8.237	0.45	3.3

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where E_p = the proton energy, W = the energy of the excited level, J = the relative intensity, Y = the absolute yield.

The γ -ray spectra were measured using scintillation spectrometer with a CsI(Te) crystal 3x2 cm, a photomultiplier and a 50-channel pulse height analyzer with a mercury-delay line as "a memory".

The angular distributions of the most intensive γ -lines corresponding to a direct transitions to the ground state have been measured at all values of the resonances, as well as the angular distributions of γ -lines at 1.26 and 6.5 Mev associated with a cascade transition from 7.774 Mev excited level to 1.26 Mev level.

The obtained angular distributions may be expressed in the form: $f(\theta) = 1 + \cos^2\theta$.

Spin values for high excited levels of the P^{31} nucleus have been derived from the angular distributions. The values of the coefficient "a" and of the spins are present ed in table 2.

Low energy γ -lines presumably corresponding to lower levels of the P^{31} nucleus with excitation energies: (0.43), 1.26; 2.23; (2.7), 3.5; 4.0 Mev, etc. have likewise been observed.

Table 2.

E_p (kev)	E (Mev)	"a"	W (Mev)	I Spin
500	1.26	-0.42	1.26	3/2
	6.50	0.83	-	
	7.77	-0.44	7.77	3/2
619.5	7.89	0	7.89	1/2
773	8.04	-0.44	8.04	3/2
939	8.20	-0.61	8.20	3/2
979.5	8.25	-0.47	8.25	3/2

THE SCATTERING OF FAST PROTONS BY NONSPHERICAL NUCLEI

S.I. DROSDOV

The scattering of fast protons by nonspherical nuclei is considered assuming the proton energy to be large as compared with the Coulomb barrier energy. The black nucleus model and the adiabatic approximation are likewise used, i.e. the proton motion is assumed to be fast in comparison with the rotation and vibration of the nucleus. In the present case the evaluation of scattering cross sections is reduced to

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the evaluation of the scattering amplitude for a fixed nucleus, the amplitude being represented by the sum of the diffractive part and the amplitude of the scattering in the electric field of the nucleus. Both parts of the amplitude are calculated on the assumption that the form of nucleus closely approximates a sphere. For nuclei possessing vibrational levels the angular distribution of elastically scattered protons coincides with that for scattering by spherical nuclei. For nuclei possessing rotational levels the angular distribution of elastically scattered protons essentially depends on the degree of nonsphericity of the nucleus.

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PHOTONUCLEAR REACTIONS

INVESTIGATION OF THE (γp) REACTION ON INTERMEDIATE WEIGHT NUCLEI

*R. Sh. AMIROV, V. V. AKINDINOV, R. M. OSOKINA,
B. S. RATNER*

Targets enriched with isotopes Cd^{114} and Cu^{65} were irradiated on the 30-Mev synchrotron. The energy and angular distributions of photoprotons were measured at several values of the maximum bremsstrahlung energy.

The results are discussed and compared with different models of nuclear reactions.

PHOTODISINTEGRATION OF LIGHT ELEMENTS

S. A. E. JOHANSSON, B. FORSMAN

Nitrogen, oxygen and fluorine have been bombarded with bremsstrahlung at various energies. The emitted protons were recorded by nuclear emulsions. The resulting proton spectra exhibit well resolved peaks corresponding to resonances in the photon absorption process. If the maximum bremsstrahlung energy is set fairly close to the threshold, only a limited number of levels are excited and the proton groups are well resolved. When the maximum energy is increased, the proton spectra become more complex but knowing the lower resonances one can calculate the contribution from the lower resonances and subtract. In this way it is possible to resolve the proton spectra step by step by using different bombarding energies. The width of the peaks supplies

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some information about the character of the photon absorption. For the strongest peaks one can plot angular distributions which furnish additional information about the resonances. In the case of oxygen the experimental results can be compared with recent calculations by Elliott and Flowers. The agreement is excellent.

ANGULAR AND ENERGY DISTRIBUTION OF PHOTO-NEUTRONS

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A.I. LEPESTKIN*

Samples of Bi, Au and Ta were irradiated with X-rays of maximum energy $E_{\max} = 14$ Mev and $E_{\max} = 18.9$ Mev.

The energy distributions of photoneutrons were measured for angles of 30° , 45° , 90° , 135° and 150° to the X-ray beam.

The energy distribution from Au, Bi and Ta shows an excess of high-energy neutrons of $\sim 10\%$ compared to the spectrum expected from statistical theory.

• The excess of high-energy neutrons was observed at $E_{\max} = 18.9$ Mev as well as at $E_{\max} = 14$ Mev.

This shows that the process of direct interaction takes place in the region of the giant resonance.

These results are in agreement with data of other authors who measured angular distribution for photoneutrons from Bi with energy > 3 Mev by the threshold detector method.

The angular distributions of photoneutrons from Bi, Au and Ta are different. The highest anisotropy is found for Bi. The results are compared with Wilkinson's calculations.

LOW ENERGY GAMMA-RAYS IN THE $F^{19}(p,\alpha\gamma)O^{16}$ REACTION

S.A.E. JOHANSSON, H. MORINAGA

The gamma-ray spectrum resulting from proton bombardment of fluorine has been carefully investigated in order to find gamma-transitions between the first four excited states in O^{16} . The transition between the 6.91 Mev and the 6.14 Mev states was

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found. Upper limits were set for the other three possible transitions. These values furnish information about the strength of the isotopic spin selection rules.

PHOTODISINTEGRATION OF HELIUM

A.N.GORBUNOV and V.M.SPIRIDONOV

Photodisintegration of helium was studied with a cloud-chamber located in the magnetic field and operating in the bremsstrahlung beam of the synchrotron of the Lebedev Physical Institute.

At 170 Mev maximum energy about 10 000 pictures were obtained. The number of photodisintegrations in helium registered on these pictures is shown below:

$\text{He}^4(\gamma p)\text{H}^3$	2835
$\text{He}^4(\gamma n)\text{He}^3$	2684
$\text{He}^4(\gamma pn)\text{D} + \text{He}^4(\gamma, 2p, 2n)$. .	547
$\text{He}^4(\gamma, 2d)$	≤ 59

The cross sections and angular distributions for γp , γn and γpnd reactions have been measured. The results show that

1) the electrical dipole absorption of the photons makes the principal contribution to the cross section for γp and γn reactions at energies below 30 Mev. At energies above 30 Mev the electrical quadrupole absorption of photons leads to a strong forward asymmetry in the angular distribution of protons for the γp reaction in the center-of-mass system. For the γn reaction this asymmetry relative to 90° c.m. is absent within the experimental errors, the angular distribution below and above 30 Mev remaining close to $\sin^2\theta$ c.m.,

2) the angular distributions of protons and neutrons for the $\text{He}^4(\gamma, pn)\text{D}$ reaction are similar to angular distributions of particles from the photodisintegration of deuteron. This shows that the two-nucleon mechanism plays an appreciable role in the photon absorption at energies above 30 Mev;

3) from the experimental cross sections for γp , γn and γpnd reactions the integral cross section for the photon absorption by the helium nucleus has been calculated. The obtained value $\sigma_{\text{int}} = \int \sigma(\omega) d\omega = 100 \pm 7$ Mev-mbn is in satisfactory agreement with the sum rule calculations for electrical dipole absorption. The experimental value

$\int \frac{\sigma_{\text{abs}}(\omega)}{\omega} d\omega = 2.4 \pm 0.15$ mbn leads to the nuclear radius parameter $r_0 = (1.12 \pm 0.04) \times 10^{-13}$ cm which is in good agreement with the value r_0 obtained from the electron scattering experiments in helium;

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4) the approximate equality of yields of the $\text{He}^4(\gamma p)\text{H}^3$ and $\text{He}^4(\gamma n)\text{He}^3$ reactions ($\frac{Y_n}{Y_p} = 0.95 \pm 0.04$) and the low yield of the $\text{He}^4(\gamma d)d$ reaction ($\frac{Y_d}{Y_p} \leq 0.02$) are in good agreement with the predictions of the charge-independence hypothesis.

PHOTODISINTEGRATION OF NUCLEI BY GAMMA - RADIATION FROM LENINGRAD
SYNCHROTRON AT 60 - 90 Mev

E.B. BAZHANOW, J.P. JAWOR, A.P. KOMAR,
L.A. KULTSHITZKY, E.D. MACHNOWSKY,
W.P. TSHIZHOW and J.M. VOLKOW.

In the last few years the research staff of the X- and γ -ray Laboratory of the Physical-Technical Institute of the USSR Academy of Sciences investigated photonuclear reactions with the following apparatus:

- a) fast overcompression cloud chamber;
- b) scintillation telescopes;
- c) ionization chambers;
- d) chambers with nuclear plates.

The following results were obtained:

- a) The angular distributions of 2 to 10 Mev protons from argon and of 1 to 15 Mev protons from neon.

Apparatus: fast overcompression cloud chamber.

- b) The energy and angular distributions of 15 to 65 Mev protons from Be, Al, Ni and Au in the laboratory system. Apparatus: scintillation telescopes.

- c) The ratios of photodeuteron yield to the yield of photoprotons from Au for $E_{\gamma_{\max}} = 70$ Mev. Apparatus: chamber with nuclear plates and scintillation telescopes.

The angular distribution of photoprotons from neon may be described by a formula of the type:

$$a + b \sin^2 \theta,$$

where $\frac{b}{a} = 2.5$, i.e. they have a maximum of angular distribution at $\theta = 90^\circ$.

The maximum of the angular distribution of protons from argon is shifted to the 70° region. The shift is due to the interference of dipole and quadrupole absorption of γ -rays.

The maximum of angular distribution of 15 to 65 Mev protons from Ni and Al is shifted towards small angles with increasing proton energy. The angular distributions of 30 to 65 Mev protons exhibits a maximum at angles $< 45^\circ$. There is no simple explanation of this fact.

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The energy distribution curves for 15 to 65 Mev protons from Be, Al, Ni and Au, and for 15 to 65 Mev deuterons from Be show sharp breaks when plotted in log-log scale. The break in the proton spectrum is in accordance with the deuteron model of Levinger.

The sharp break in the deuteron spectrum seems to be in accordance with the α particle model of γ -ray absorption.

Investigations of d-d, p-p and p-n coincidences are in progress.

PHOTODISINTEGRATION OF DEUTERON AT 50-150 Mev

U.A. ALEXANDROV, N.B. DELONE, L.I. SLOVOHO-
TOV, G.A. SOKOL, L.N. SHTARKOV

The reaction of deuteron photodisintegration has been investigated at the 265-Mev synchrotron of the P.N. Lebedev Physical Institute, USSR Academy of Sciences. Protons from D_2O and H_2O targets have been detected by a two-counter telescope.

The differential cross section has been measured for six points of photon energies from 50 to 150 Mev and for seven points of angles from 22.5 to 157.5 degrees in the laboratory system. The obtained values of cross sections in the center of mass system are listed in Table 1. Energy uncertainty is about ± 7.5 Mev. Standart statistic errors are about 10%. The systematic uncertainty of the absolute cross section value is about 15%.

Table 1.

Photon energies, Mev	Angles and differential cross section, μ barn/sterad.						
54	25°	50°	74°	97°	118°	139°	160°
	6.0	11.2	13.3	-	9.1	5.7	3.7
70	26°	51°	75°	98°	119°	140°	160°
	5.5	11.1	10.8	-	6.8	4.1	3.0
88	27°	52°	76°	99°	120°	140°	160°
	7.0	9.8	9.0	6.1	6.6	3.5	5.2
110	27°	53°	77°	100°	121°	141°	161°
	6.7	8.1	7.7	5.7	4.6	4.0	2.8
129	27°	54°	78°	100°	122°	142°	161°
	7.3	5.8	4.9	4.9	4.7	3.6	2.9
148	28°	54°	79°	101°	122°	142°	161°
	6.2	6.9	5.6	5.4	5.3	3.4	4.3

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The angle distributions in the center of mass system are in satisfactory agreement with the form $\frac{d\sigma}{d\Omega} = \left(\frac{d\sigma}{d\Omega}\right)_{\text{M.G.}} + P + Q \cdot \cos\theta$, where $\left(\frac{d\sigma}{d\Omega}\right)_{\text{M.G.}}$ is the differential cross section obtained by Marshall and Guth, P and Q are approximation parameters. The values of parameters obtained by the least square method are listed in table 2. The value $4\pi \cdot P$ is the total cross section of transitions leading to isotropic angle distribution. σ_t is the value of the total cross section of photodisintegration calculated from the equation $\sigma_t = (\sigma_t)_{\text{M.G.}} + 4\pi \cdot P$.

Table 2.

Photon energies, Mev	P $\mu\text{barn/ster.}$	Q $\mu\text{barn/ster.}$	$4\pi \cdot P$ μbarn	σ_t μbarn	$\pm\Delta\sigma_t$ μbarn
54	1.30	-0.76	16.3	129.1	5.1
70	2.72	0.92	34.2	105.2	3.6
88	3.50	0.81	44.2	89.5	4.6
110	3.80	1.11	47.8	77.2	3.5
128	3.27	0.42	41.1	61.9	3.6
148	4.27	1.00	53.7	69.1	4.1

Interpretation of data is based on Marshall and Guth's calculations and on Wilson's idea about photodisintegration by meson production and reabsorption. Calculated values of the total cross section of multipole transitions are in reasonable agreement with Wilson's results and Nagahara and Fudsimura's calculations.

SOME PHOTOREACTIONS ON LIGHT NUCLEI

V. N. MAIKOV

A number of reactions on C^{12} , N^{14} and O^{16} nuclei, produced in photoemulsions by Bremsstrahlung spectrum with maximum energies of 150 Mev and 250 Mev are investigated.

1. $\text{C}^{12}(\gamma, 3\alpha)$ and $\text{C}^{16}(\gamma, 4\alpha)$ reactions

340 events of oxygen nucleus disintegration and 180 events of hydrogen disintegration have been observed. The dependence of the reaction cross section on the γ -ray

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energy has been determined. No events have been found in which the photon energy exceeded > 50 Mev. The sharp decrease in the reaction cross section in the 35 Mev energy range may possibly be connected with the competition of $(\gamma, p\alpha)$ reactions on C^{12} and O^{16} nuclei.

2. $C^{12}(\gamma, p\alpha)$, $N^{14}(\gamma, p\alpha)$ and $O^{16}(\gamma, p\alpha)$ reactions

473, 209 and 316 stars have been found corresponding to the three above reactions respectively. Dependence of cross sections on γ -ray energy, angular and energy distributions of disintegration products have been obtained. The analysis of experimental data from the point of view of the γ -ray energy distribution between the reaction products shows that:

- a) the interactions of γ -rays with carbon and oxygen nuclei leading to the above reactions are apparently of the same nature;
- b) the absorption of photons by nuclei varies with the increase of γ -ray energy. In the energy region $E_\gamma = 25 - 50$ Mev the energy of the absorbed photon is distributed "symmetrically" between the reaction products so that the energy distribution of particles is determined only by the phase space volume. The results are not in contradiction with the model of series decay, but may likewise be explained from the point of view of simultaneous disintegration into three non-interacting particles;
- c) in the energy region $E_\gamma > 50$ Mev, protons are energetically favoured in comparison with other particles and carry off from 60 to 90 per cent of the available energy $E_o = E_\gamma - E_{bound}$. The interaction of the photon with the nuclei is apparently local (direct photoeffect). The formation of an intermediate nucleus in the reaction is not excluded.

3. $C^{12}(\gamma, p\alpha)2\alpha$ reaction

Preliminary results have been obtained. The integral cross section of the reaction between 30 and 80 Mev is 5 mb/Mev. The energy distributions of protons and tritons have maxima near 4 Mev and 3 Mev respectively. The angular distribution of protons shows a small isotropic part and a forward shift of maximum from 90° . The investigated reactions play an important part in photostar production. Thus, the cross sections of $C^{12}(\gamma, p\alpha)Li^7$ and $C^{12}(\gamma, pt)2\alpha$ reactions in the 30-80 Mev energy range contribute ~ 50 per cent of the total photostar production.

ON THE WIDTH OF THE GIANT RESONANCE IN PHOTONUCLEAR REACTIONS

S.A.E. JOHANSSON

The shape of the giant resonance in photonuclear reactions will be discussed in terms of various models. The available experimental material is reviewed. It is shown in what cases the measured cross section curves give the shape of the total cross

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section curve for photon absorption. It turns out that there exists a good correlation between the width of the giant resonance and the shape of the nucleus. Deformed nuclei have a considerably broader resonance than other ones. This fact is easiest to explain by the collective model for photonuclear reactions.

ON THE MECHANISM OF GIANT RESONANCE

V.V.DARAGAN, Yu.M.SHIROKOV

A two-nucleon model is suggested for the explanation of the Giant Resonance in the photo-nuclear reactions. According to the model, the photon is absorbed by two mutually interacting nucleons. The existence of this interaction in the giant resonance energy interval is indicated by the occurrence of the direct nucleon-nucleon interaction in this region. The model agrees with the principal experimental data on the giant resonance. Particularly, it leads to the correct position of the resonance maximum. Our considerations include the one-nucleon model suggested by Wilkinson, which also contributes to the absorption cross section but plays an important role in the energy region below the giant resonance. Therefore if the one-nucleon maximum is above the photo nucleon threshold the absorption cross section must possess in general two dipole maxima. The existence of the two maxima has been observed in the experiments on C^{13} and N^{14} .

INTERACTION OF PHOTONS WITH POLARIZED NUCLEI

A.M.BALDIN

In the numerous former investigations of interaction of photons with nuclei the influence of nuclear spin on this interaction was not considered. It may be shown that nuclear spin can play an essential role in such processes.

The general expression for the electric dipole scattering amplitude has the form:

$$S = S_1 (\vec{\lambda} \hat{I}) (\vec{\lambda}' \hat{I}) + S_1^* (\vec{\lambda}' \hat{I}) (\vec{\lambda} \hat{I}) + S_3 (\vec{\lambda} \vec{\lambda}'),$$

where the $\vec{\lambda}$ and $\vec{\lambda}'$ = polarization vectors of the incoming and outgoing photons respectively, \hat{I} = operator of nuclear spin, S_1 and S_3 = parameters independent of $\vec{\lambda}$ and scattering angles.

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As follows from calculations the angular distribution of the scattered photons contains terms of the type $(1 - \sin^2\theta \cos^2\varphi)$, where θ = scattering angle, φ = azimuthal scattering angle at $S_1 \neq 0$. The value of such terms is dependent on the relationship between S_1 and S_3 and on magnitude of nuclear spin.

The cross section of any photonuclear reaction on nuclei with large spins is dependent on orientation of the spin with respect to the direction of the photon beam.

The magnitude of the above mentioned effects (the relationship between parameters such as S_1 and S_3) depends to a high degree on the accepted model. The comparison of experimental data with results of calculations with different models can help in understanding the mechanism of interaction of electromagnetic field with nuclei and the nature of nuclear spin.

PHOTONUCLEAR REACTIONS

D.H. WILKINSON

A brief survey is presented of the chief facts of nuclear photodisintegration especially in the region of the giant resonance ($E_\gamma < 30$ Mev). The systematics of the various processes are sketched and related to other parameters that characterize the nuclear system.

The two chief models so far adduced to account for the phenomena - the model of nuclear polarization and the shell model - are described with particular reference to refinements recently introduced into each. Recent attempts to reconcile the apparently conflicting physical pictures lying behind these two models are described and their possible equivalence is indicated.

Experiments in which detailed comparison appears possible with one or other model (in the light elements for the shell model and in the heavy elements for the collective model) are reported. A qualitative account is given of certain aspects of the photonuclear process at slightly higher energies.

INTERPRETATION OF THE GIANT RESONANCE PHENOMENON IN THE PHOTODISINTEGRATION OF O^{16}

B.H. FLOWERS

A shell model calculation has been performed for the odd parity states of O^{16} which arise from the almost degenerate configurations $p^{-1}s$ and $p^{-1}d$. In terms of these states a natural explanation can be given of the giant resonance, of its fine structure, and of the associated nucleon emission characteristics, all of which lend strong support to Wilkinson's picture of the giant resonance phenomenon.

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NUCLEAR REACTIONS INDUCED BY HEAVY IONS

NUCLEAR REACTIONS INDUCED BY HEAVY IONS

G. N. FLEROV

It follows from experimental data that in the interaction of heavy ions with nuclei the formation of excited compound nuclei plays a predominant role, the excitation energy reaching several hundred Mev. The production of such highly excited nuclei by any other method is impossible.

The characteristic feature of the reactions induced by heavy ions is that compound nuclei receive a large angular momentum. The investigation of highly excited nuclei with large angular momenta is one of a whole series of investigations using heavy ions.

The interaction of heavy ions with nuclei gives rise to an exchange of nucleons or complexes of nucleons between interacting nuclei.

These processes proceed at the periphery of the nucleus and their investigation may furnish information on the surface structure of the nucleus. In addition to the above mentioned lines of investigation, heavy ions may be used for the production of new isomers (both by Coulomb excitation and by means of compound nuclei formation), new isotopes and elements. Recently the interaction of heavy ions with different nuclei has been investigated in several laboratories, the greater part of these investigations being devoted to the solution of the problem whether the formation of compound nuclei is the principal process in the reactions induced by heavy ions.

The process of nucleon exchange has been investigated and some new isotopes and elements produced. The greater part of this work has been performed using a beam of nonmonoenergetic ions.

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Intensive beams of monoenergetic carbon, nitrogen and oxygen ions with energies upwards of 100 Mev were obtained in 1956. It has made possible a series of new investigations, from which a sufficiently complete idea about the character of the nuclear reactions induced by heavy ions may be derived.

It may be assumed that the formation of compound nucleus is the predominant process in the reactions with heavy ions.

Heavy nuclei are characterized by evaporation of neutrons and fission. For light and intermediate nuclei the emission of a number of charged particles, besides neutrons, has been observed.

INTERACTION BETWEEN NITROGEN IONS AND HEAVY ELEMENT NUCLEI

S.A. BARABOSHKIN, V.A. DRUIN, A.S. KAR-
MIAN, S.M. POLIKANOV, G.N. FLEROV

The monoenergetic 115-Mev beam of nitrogen ions N_{14}^{+5} from the cyclotron of the Atomic Energy Institute, USSR Academy of Sciences, has been used to investigate the dependence of the cross sections on nitrogen energy for Au (N, 4n), Au(N, 5n), Au(N, 6n) reactions.

In accordance with the theory of competitive processes curves with pronounced peaks have been obtained.

The measured Au(N, 4n), Au(N, 5n), Au(N, 6n) excitation functions have been compared to the excitation functions predicted by the compound nucleus theory. The excitation functions from this experiment are displaced in energy by 10-15 Mev which is not predicted by the theory.

It is possible that the observed energy shift may be explained by a very high angular momentum imparted to the heavy compound nucleus by the 100 Mev N^{14} nucleus.

Experiments in fission of U^{235} , U^{238} , Bi, Au and Re induced by accelerated nitrogen ions are likewise described. The measurements have been conducted with an ionization chamber.

The dependence of the fission cross sections for these nuclei on the nitrogen ion energy has been studied in the energy range from 70 to 110 Mev. The obtained results are analyzed from the viewpoint of the influence of the Z and A parameters and the excitation energy on fission probability.

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STRIPPING REACTION PRODUCED BY ACCELERATED
IONS N_{14} ON SOME NUCLEI

V.V. VOLKOV, A.S. PASIUK, G.N. FLEROV

The formation of a radioactive isotope N_{13} has been observed due to stripping reaction under bombardment of thin Al, Ni, Cu, Ag, Co, Sn and Pt foils by nitrogen ions N_{14}^{+5} ($E \sim 100$ Mev) from the cyclotron of the Atomic Energy Institute, USSR Academy of Sciences. The angular distribution of N_{13} is characterized by narrow interval angles of particle emission ($20^\circ - 30^\circ$). For the incident N_{14} energy of about 60 Mev an intensity maximum of N_{13} for Al at about 10° , for Ni - at 30° , for Sn and Ag - at 60° has been observed. The cross section of N_{13} formation for Al and Ni has been measured in the energy range from 30 Mev to 105 Mev. The cross section varies but slightly at energies higher than the Coulomb barrier and is 10 mb for Al and 30 mb for Ni in this range.

MASS DISTRIBUTION OF FISSION FRAGMENTS
FORMED BY NITROGEN IONS ON GOLD AND URANIUM NUCLEI

N.I. TARANTIN, Ju. B. GERLIT, L.I. GUSEVA,
B.F. MYASOEDOV, K.V. FILIPPOVA, G.N. FLEROV

In the present paper the mass spectrum of fission products formed on irradiation of 30 μ thick gold and uranium targets with 115 Mev N^{14} ions has been investigated. Fourteen different elements have been chemically separated from the irradiated targets. The isolated radioisotopes have been identified by the half-life, beta-energy and the sign of the beta-particle charge.

Mass distribution of fission fragments from the gold target irradiated with nitrogen ions is represented by a single curve with a broad maximum. The width of the curve at half-maximum is about 20 mass units. The maximum of the curve corresponds to $A \sim 100$.

Mass spectrum of fission fragments formed on irradiation of uranium with nitrogen ions is found to be considerably more narrow. The width of the curve at half-maximum contains more than 50 mass units.

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THE FISSION BARRIER OF ROTATING NUCLEI

G. A. PICK-PICHACK

The influence of nuclear rotation on the fission barrier height is calculated using the nuclear drop model. This influence is connected with the moment of inertia change due to deformation. For large angular momentum $\geq 50 \hbar$ (such nuclei are formed by the capture of heavy ions by atomic nuclei) the rotation essentially influences the fission barrier height. The nucleus becomes unstable owing to fission for a critical value of the angular momentum. The dependence of mass distribution of fragments on the momentum is slight.

STATISTICAL THEORY OF ANGULAR DISTRIBUTION OF FISSION FRAGMENTS

V. M. STRUTINSKY

The angular distribution of fission fragments is considered in case when the angular moment of compound system is distributed among a large number of nucleons and one can describe nucleus with statistical model approximation. The distribution of K values (where K is the projection of angular moment of "transition" nucleus in the direction of the symmetry axis) is calculated. The state with $K=0$ turns out to be the most probable one which gives maxima in $\theta=0, \pi$ directions for fission fragment angular distribution in nucleon - induced fission and in $\theta=\frac{\pi}{2}$ direction in case of photofission. The comparison with experimental data allows to determine the value of the moment of inertia in relation to symmetry axis. Fong's theory of asymmetrical fission is discussed from the point of view of angular distribution of fragments.

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NUCLEAR MODELS

THE OPTICAL MODEL OF THE NUCLEUS

P. E. NEMIROVSKY

The up-to-date state of the theory of neutron interaction with nuclei at low and intermediate energies is analyzed. The processes at very low energies are discussed, the strength function and potential scattering data are compared with theory.

The total cross sections and angular distributions are considered in the usual scheme, and also taking account of the spin - orbit forces. It is shown that addition of the spin - orbit interaction makes the agreement with experiment better. For 400 kev neutrons the theory is compared with polarization experiments. For higher energies the estimation of polarization is made.

The variation of optical parameters (the well depth, the absorption factor) with energy is discussed.

For 14 - 20 Mev neutron energies several theoretical papers dealing with experimental data are critically discussed.

Finally, some considerations about the relation between optical potential and shell model - potential are advanced.

Time 40 minutes.

INTERACTION OF SLOW NEUTRONS WITH SPHERICAL AND ELONGATED NUCLEI

V. V. VLADIMIRSKY

The paper reports on the results of calculations of slow neutron interaction with elongated nuclei, according to the cloudy crystal model of the nucleus, carried out by V. V. Vladimirovsky and by I. L. Ilyina, and on interaction of slow neutrons with nuclei,

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as reviewed by V.V. Vladimirovsky, I.A. Radkevich, V.V. Sokolovsky and A.A. Panov. The solution of the problem of neutron motion in a complex potential well for an elongated nucleus has shown that the position and the shape of the giant neutron absorption resonances, depending on the atomic number, changes appreciably in the transition from spherical to elongated nuclei. This enables one to explain qualitatively the washed out character of the giant resonance near $A=150$ without recourse to an increase of the imaginary part of the complex potential.

TOTAL NEUTRON CROSS SECTIONS AT 1-14 Mev
ACCORDING TO THE OPTICAL MODEL OF THE NUCLEUS

E.V. INOPIN

Total neutron cross sections in the 1-14 Mev range for Fe, Sn, Pb nuclei have been calculated according to the optical model of the nucleus with potential in the form of a rectangular well.

A good agreement with experimental data has been obtained for the three nuclei belonging to three different regions of the periodic table.

OPTICAL MODEL OF NUCLEONS - NUCLEI INTERACTION
IN THE RESONANCE REGION OF THE COMPOUND NUCLEUS

V.M. AGRANOVICH, A.S. DAVYDOV

The energy dependence of the real and imaginary parts of the effective potential of the optical model is investigated taking into account all states of the compound nucleus. It is shown that only the real part of the effective potential of the optical model is the smooth function of the neutron energy in the resonance region of the compound nucleus.

In the computation of the imaginary part of the effective potential the deviation from the potential of the optical model was considered as a perturbation leading to the compound nucleus formation. Interpretation is given for the broad resonances in the interaction between neutrons and nuclei.

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Contrary to the theory of Lane, Thomas and Wigner, it is shown that the imaginary part of the potential in the resonance region is considerably smaller than the root square of the second moment and essentially depends on the level density of the compound nucleus. This result coincides with those of Bloch.

A METHOD FOR LIGHT NUCLEI LEVELS CALCULATION

YU. M. SHIROKOV, K. A. TUMANOV, W. W. BALASHOV,
O. P. DOROFYEV, N. N. KALITKIN, A. K. KAMINSKY,
YU. F. SMIRNOV,

A method for deriving ground and first excited energy levels and wave functions of light nuclei is suggested. Charge-independent nucleon-nucleon interaction is assumed, many-body forces being neglected. The Coulomb energies are taken into consideration separately. In contrast to the usual procedure a form of two-body interaction hamiltonian is not preset. The matrix elements of this hamiltonian necessary for the calculation are derived from the experimental values of nuclear energy levels.

The problem of separation of nucleus centre-mass movement is solved by subtraction of kinetic energy of the whole nucleus from the complete hamiltonian. It is thus possible not to apply Jacoby coordinates using ordinary antisymmetrical functions.

A nucleus wave function is given by resolution into the configurations of harmonic oscillator states. This resolution is believed to converge rapidly with regard to the main quantum number and so it is cut short, all the allowed configurations within the taken quantum numbers (1s, 1p - shells for the nuclei to 0) being considered. Then the Schrödinger equations for the different nuclei and levels are formed in this oscillator representation. Matrix elements of the interaction hamiltonian can be expressed in terms of two-body configuration matrix elements. There are only 32 such elements within 1s, 1p-states (spin and isobaric spin to be taken into account). Owing to the conservation laws for two-body interaction, these 32 elements are not independent. One can obtain 16 independent matrix elements by excluding the movement of centre of inertia of two interacting nucleons by Talmi method. The matrix elements of Coulomb interaction are calculated in the same way.

Thus for the ground and excited states of light nuclei we have secular equations including as unknown variables 16 parameters of nucleon-nucleon interaction. If one considers only the states with undestroyed S-shell for nuclei between He^4 and O^{16} three parameters out of sixteen drop out of this equation. The equations include also two parameters associated with nuclear dimensions.

The derived system of equations is solved using computing machine technique.

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INTERMEDIATE ENERGY NEUTRON SCATTERING
BY NON-SPHERICAL NUCLEI

E. V. INOPIN

In the work on neutron scattering by non-spherical nuclei examination was carried out either in the approximation $kR \gg 1$, where k is neutron wave-vector and R , the nucleus radius, i.e. for high energy neutrons or according to the perturbation theory which is probably incorrect in this case.

The author considers the case of neutrons of intermediate energy of a few Mev. This case is interesting from the point of view of comparison with the experiment. The calculations are made in the adiabatic approximation, where the nucleus is considered to be at rest during the time of collision. The approximation is valid when

$$\frac{\epsilon}{E_n} \cdot kR \ll 1,$$

where ϵ is the energy of the first excited rotation state,
 E_n is the energy of the incident neutron.

In the adiabatic approximation the case is reduced to the problem of the particle scattering in a given field.

The latter is considered as constant inside the nucleus which has the rotation ellipsoid (spheroidal) form, and as equal to zero outside the nucleus. This problem is solved with the aid of well-known and partially tabulated spheroidal functions. The necessary averaging is performed over the nucleus orientations and expressions for the cross section of the elastic and inelastic scattering are obtained.

A numerical example is computed showing the effect of non-sphericity of the nucleus to be considerable.

THE ROLE OF PAIRING INTERACTION ON FORMATION OF DEFORMED NUCLEI

B. L. BIRBRAIR AND L. A. SLIV

The condition of static deformation of nuclei is observed. If we take into account only the states of nucleons outside closed shells then, as is known, the energy decreases almost linearly with deformation.

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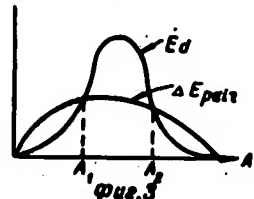
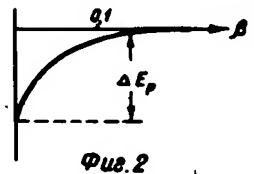
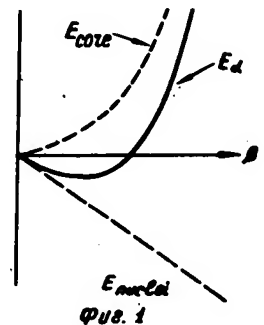
The core deformation energy increases quadratically with deformation. That is the reason why for every nucleus a minimum energy deformation exists and all nuclei would be deformed (Fig.1).

But we have to take into consideration a new factor: specific pairing energy which decreases when we go over from spherical to deformed state of nucleus. The shape of pairing interaction curve for two nucleons is calculated as perturbation using δ -forces and other short-range forces (Fig.2).

The difference ΔE_p can be taken from mass-defect data which give about 2 Mev for light and 0.5 Mev for heavy nuclei.

All the three factors taken together create such a situation for nuclei between closed shells that nuclei are deformed only in definite region A_1 - A_2 between closed shells (Fig.3).

If we assume for ΔE_p (per one pair) 0.7 Mev in rare-earth region and 0.5 Mev for heavy elements we get the correct boundaries for deformed nuclei. We have also found out that deformed states are theoretically possible only in three (known) regions throughout the periodical table.



COLLECTIVE EXCITATIONS OF EVEN-EVEN ATOMIC NUCLEI

A. S. DAVYDOV, G. F. FILIPPOV

The problem of collective excitations in an even-even nucleus possessing axial symmetry is considered without assuming the rotational energy to be much smaller than the vibrational energy.

The energy levels of the collective excitations and the succession of spins have been computed for different parameters of deformation. It is shown that the energy of the collective excitations can be represented as the function of only two parameters: $\omega_0 = \sqrt{\frac{C}{B}}$ and $\delta = \beta_0 \left(\frac{BC}{h^2} \right)^{1/4}$. In the $\delta > 2.5$ region the excitation spectrum can be represented as a system of rotational-vibrational bands. In the $\delta < 2.5$ region the separation of the excitation energy into rotational energy and vibrational energy

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is no longer possible. In the $\delta < 0.4$ region the occurrence of peculiar excited states of the nucleus corresponding to negative quadrupole moments of the excited states might be expected.

Comparison with experiment is given.

ENERGY LEVELS OF NUCLEONS IN A NONSPHERICAL NUCLEUS
ACCORDING TO THE INDEPENDENT PARTICLE MODEL

D. A. ZAIKIN

An asymptotic expression is obtained for the energy levels of nucleons in a spheroidal box. The expression is valid for large values of $K^2 f^2$, where K is the wave number of the nucleon and f is half the distance between the ellipsoid foci. The results obtained are used to calculate level schemes for nucleons in ellipsoidal nuclei with axes ratios ranging from 0.6:1 (oblate ellipsoid) to 2:1 (prolate ellipsoid). A method for taking into account the finite well depth and spin-orbit coupling is proposed.

ELECTROMAGNETIC TRANSITIONS AND ISOTOPIC SPIN IN THE LIGHT
NUCLEI

D. H. WILKINSON

The empirical evidence on electromagnetic transitions in the light nuclei ($A < 20$) is presented. It is shown that $E1$ and $M1$ transitions conform closely to the prediction of the independent particle model but that $E2$ transitions are usually enhanced and give clear evidence for some collective motion in the light nuclei. The $E1$ transitions forbidden by the isotopic spin selection rule are markedly slower than the allowed transitions but the separation between the two groups is not complete. There is an apparent tendency for $E1$ and $M1$ transitions of lower energy to be relatively faster than those of higher energy but this effect may be spurious.

The evidence on the purity of isotopic spin states is reviewed. Attempts are made to extract quantitative information about the impurities from the data and to get some idea of H_{TT}^0 , the Coulomb matrix element responsible for mixing T and T' . A strong correlation is observed between H^0 and O_n^2 the reduced width for nucleon emission to the ground state of the parent nucleus. Other evidence relating to charge independence is reviewed and quantitative recommendations are made on all these points.

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**EXPERIMENTS WITH POLARIZED NEUTRONS
AND THE OPTICAL MODEL OF THE NUCLEUS**

H. H. BARSHALL

The polarization of 380-kev and 980-kev neutrons scattered elastically through various angles by intermediate and heavy nuclei was measured. The neutrons were produced in the $\text{Li}(p,n)$ reaction and their polarization was determined with an oxygen analyzer. The polarization of the neutrons emitted at 50° from the $\text{Li}(p,n)$ reaction was found to be about 30 percent at neutron energies from 350 to 1200 kev. The polarization of the neutrons scattered from the heavy elements varies smoothly with atomic weight and reaches a maximum of 20 percent. It is hoped that these results can be used for determining the nature of a spin-orbit term in the optical potential, but so far no adequate calculations have been performed.

**THE RELATION BETWEEN COLLECTIVE MOTIONS
AND INDEPENDENT PARTICLE MOTIONS IN NUCLEI**

B. H. FLOWERS

It is obvious that collective motions can be expressed in terms of sufficiently complicated configurational interaction. It has been found possible, however, to obtain states having simple rotational properties by means of suitably chosen shell model wave functions which employ only the mixing of degenerate configurations implicit in a three dimensional harmonic oscillator. Moreover, these states are very nearly eigenstates of a short range interaction in the limit of many particles outside of closed shells. A simple physical picture will therefore be offered of the development of rotational spectra from independent particle states.

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